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EFFECTS OF CHANGING THE PROPORTIONS OF AUTOMOTIVE DISTILLATE AND GASOLINE PRODUCED BY PETROLEUM REFINING

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control
Alternative Automotive Power Systems Division
Ann Arbor, Michigan 48105

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FOREWORD

This study was performed pursuant to an amendment to Contract No. 68-01-2112: "Feasibility Study of Alternative Fuels for Automotive Transportation"; published as Report No. EPA-460/3-74-009 of June 1974.

TABLE OF CONTENTS

APPENDICES

1. SUMMARY

This study examines the effects of changing the proportions of automotive distillate fuel and gasoline produced by refining petroleum. The study applies quantitatively to a U.S. petroleum refinery that would come on stream in the 1990-2000 time-frame.

Currently, U.S. petroleum refineries emphasize the production of gasoline relative to automotive distillate fuel. The current ratio is about 12:1 on a volume basis or about 10:1 on a BTU basis. Refinery process calculations indicate that significant savings are theoretically possible if current practice were able to shift towards equal quantities of automotive distillate and gasoline. The maximum theoretical saving is about 2% of the crude oil fed to the refinery. There would also be investment and operating cost savings in new refineries designed specifically to produce equal quantities of the two types of automotive fuel:

	Range of Maximum Saving
Cost of automotive fuel	10 to 13 cents per million BTU of automotive fuel
" " " "	1.2 to 1.5 cents per gallon " " "
Investment	$83 to $100 per million BTU of calendar day of capacity to produce automotive fuels

In terms of the current delivered cost of imported crude oil, the maximum theoretical saving in crude oil (as measured by a lower requirement for refinery process energy) is about $1 billion per year. However, the extent to which such a future saving may be possible is not established by this study. The external impacts of major changes in gasoline/distillate ratio need to be analyzed, and the incentive for such an analysis appears substantial.

One significant external impact is expected to be on the availability of petrochemical feedstocks. It would be unwise to become committed to a major change in refining practice without first evaluating the possible impacts on the chemical industry. This, however, is not the only industry that could be affected. Almost all users of fuel oils create a competitive demand for petroleum that, in this study, is converted preferentially to automotive distillate fuel.

Additionally, the "optimum" (internal to the refining of average quality conventional crude oil) of producing approximately equal quantities of automotive distillate and gasoline is not expected to apply quantitatively to the processing of syncrudes derived from coal or oil shale. The gasoline/automotive distillate ratio for minimum investment and process energy consumption is expected to be closer to 2:1 than to the 1:1 ratio calculated for conventional crude oil.

2. OBJECTIVES

Several automotive engines, under study by EPA and others, are capable of using distillate fuel rather than gasoline. The engine types include the diesel, the automotive gas turbine, the Stirling, and certain of the stratified change designs. The objective is to develop engines with improved emission characteristics and fuel economy. There would be a further advantage if the production of the requisite amount of automotive distillate fuel from petroleum and/or synthetic crudes consumes less energy than that needed to produce gasoline.

EPA is interested in learning whether the shift to increased distillate production, associated with the widespread use of new engines requiring distillate fuel, would:

(1) result in significant improvements in resource utilization;

(2) cause other impacts of significance (positive or negative).

At the level of effort agreed upon, the study cannot answer all the questions that it raises. In such cases, the objective is to provide sufficient information to allow EPA to decide whether additional work would be justified.

The time-frame for the study is 1990-2000. This is the period during which major market penetration of a new automotive power plant could occur if it were introduced in the early 1980's and then developed according to a typical market penetration model[1].

3. BASIS AND APPROACH

3.1. Key Assumptions

(1) If a new automotive power plant requiring distillate fuel were to be introduced in the early 1980's, major market penetration could occur in the 1990-2000 time-frame.

(2) Post-1980, petroleum-derived products may be supplemented to an increasing extent with comparable products derived from coal and oil shale.

(3) By the 1990's, the use of oil for base load power generation will be declining rapidly, thereby increasing the theoretical availability of liquid fuels to the transportation sector.

3.2. Co-product Considerations

Distillate fuels and gasoline are co-products of petroleum refining. If the yield structure is changed in order to make more distillate and less gasoline, multiple changes in refinery processing may be needed. This will affect the amount of energy used in such processing for a given amount of product output. Thus, changing the product slate will change the crude oil requirement. Stated another way, for a given quantity of crude oil input there will be different total quantities of products output depending on exactly what is produced, i.e., on the relative proportions of the various products.

3.3. Approach

An optimum ratio of gasoline to middle distillate does not exist per se. Rather, the ratio should be viewed in the context of energy supply and demand as a whole because:

(1) Petroleum refineries must meet the demand for many types of petroleum products, not just automotive fuels. Such requirements limit the flexibility with which the gasoline/distillate ratio may be varied, and also determine how much of the distillate produced is available for automotive use.

(2) Other forms of energy can substitute for petroleum products in many applications, thereby affecting the constraints referred to in (1).

Thus, in the present limited study, a dual approach is used:

(1) A quantitative examination of how petroleum refining operations would be affected by substantial changes in gasoline/distillate ratio.

(2) A qualitative examination of the possible impacts, external to the refinery, of different ratios.

For the purpose of (1), it is not necessary to know the size of the future vehicle population nor what the total demand for automotive fuels will be. Instead, the effects of changing the gasoline/distillate ratio may be shown relative to a base case. This approach establishes what may be technically feasible in a typical refinery. Also, it determines the hypothetical ratio that would minimize refining investment and/or consumption of process energy. However, the approach does not reveal whether the hypothetical ratio would be practical in view of the petroleum and energy situation in total. Only by a full examination of (2) can it be determined whether the calculated ratio is a true optimum or merely an unrealistic suboptimization of refinery processing--unrealistic because the externalities would prevent refineries from being so operated.

The report is structured so that the results of the calculations concerned with (1) are presented first. However, the reader should bear in mind that the implications of the refinery processing calculations are qualified by the externalities discussed subsequently.

Those wishing to approach the matter from the vantage point of current domestic refining operations may wish to read Appendix 1 before proceeding to Section 4.

4. RESULTS AND DISCUSSION OF REFINING CALCULATIONS

4.1. Parametric Cases

Two sets of parametric calculations were made:

(1) one base case involved an 8% yield of heavy fuel oil;

(2) the other base case involved a 22% yield of heavy fuel oil.

These cases simulate (1) the current level of fuel oil production by domestic refineries, and (2) the current level of domestic fuel oil consumption as a percentage of total petroleum consumption, after taking petroleum imports into consideration.

Starting from each base case, parametric calculations were made:

(1) The output of automotive distillate fuel was increased, while the output of motor gasoline was correspondingly reduced.

(2) The BTU's in the total automotive fuel product (distillate plus gasoline) were kept constant.

(3) The output of all other products was kept constant on a BTU basis (see Table 1).

(4) The crude oil charge* was allowed to vary in order to reflect any conservation of resources (as measured by savings in energy consumed by the refining processes) due to the changes in the relative production of automotive distillate and gasoline.

Details of the refining processes used and the manufacturing specifications for each product are given in Appendix 2. For each parametric case, a linear program was used to calculate the minimum cost of making the required product yields in a refinery with a nominal crude oil charging capacity of 100 MB/D (100,000 barrels per day).

4.2. Results of Refining Calculations

The effects of increasing automotive distillate fuel production at the expense of motor gasoline were measured in terms of changes in:

- process energy consumption;

- cost of automotive fuels;

- refining investment.

* The crude oil fed to the refinery.

TABLE 1

Product Yields in Base Cases

	Product Percentages	
• Low Fuel Oil Case (8%)	BTU Basis	Vol. Basis*
LPG	2.2	3.2
Motor gasoline	54.3	57.0
Aviation turbo fuel	9.5	9.2
Automotive dist. fuel	6.1ø	5.6
Other middle dist.	19.7	17.9
Fuel oil	8.2	7.2
• High Fuel Oil Case (22%)	BTU Basis	Vol. Basis**
LPG	1.9	2.8
Motor gasoline	46.0	49.1
Aviation turbo fuel	8.0	7.9
Automotive dist. fuel	5.1ø	4.8
Other middle dist.	16.7	15.4
Fuel oil	22.3	20.0

* These yields correspond to those for fuel products manufactured by domestic refineries in 1972.(2)

** The higher fuel oil case takes account of imports of heavy fuel oil, treating such imports as if they were produced by domestic refineries. The yields of the other fuel products were prorated downwardly from those in the low fuel oil case in order to allow for the higher percentage of fuel oil assumed in the aggregate refinery output.

ø In each base case, the yield of automotive distillate fuel is 10% (on BTU basis) of the total output of automotive fuel (i.e., automotive distillate plus gasoline). This simulates current production by domestic refineries (low fuel oil case) and current supply including imports (high fuel oil case).

The changes, relative to the two base cases (8% and 22% yield of heavy fuel oil), are reported in terms of savings in Table 2. The negative values in the last column signify that the calculated energy consumption, automotive fuel cost, or investment was higher than in the pertinent base case. It will be seen that all of the other conditions gave savings relative to the base cases. For ease of comparison, the data from Table 2 are plotted in Figures 1 and 2. The principal points to be noted are:

(1) In both the low and high fuel oil cases, maximum savings were obtained when the amount of automotive distillate produced was approximately half the total automotive fuel output (on a BTU basis).

(2) Beyond a 55/45 ratio of automotive distillate/gasoline, process energy consumption, automotive fuel cost, and investment all increased.

(3) At about a 70/30 ratio, energy consumption and costs approximated the base case values.

(4) Beyond the 70/30 automotive distillate/gasoline ratio, energy consumption and costs increased sharply (i.e., the rate of increase accelerated). Slightly beyond a 73/27 ratio, the computer calculations became "infeasible," thereby implying that the physical maximum percentage of automotive distillate fuel had been exceeded.*

(5) For both levels of fuel oil yield, the maximum savings in process energy were about 2% relative to the respective base cases. The absolute level of process energy consumption was higher in the low fuel oil yield cases because a higher level of conversion processing is involved.

(6) The 2% maximum saving in process energy is equivalent to a 2% saving in crude oil. However, if related to the total production of automotive fuel, the percentage would be almost doubled (because the total automotive fuel output was 60% and 51%, respectively, of the total product output of the refinery). It is reasonable to attribute the energy saving entirely to automotive fuel because the yields of all other products were kept constant.

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* In a completely artificial way the percentage of automotive distillate fuel could be 100% by the simple, but unconscionable, expedient of destroying gasoline product by flaring naphtha. The computer program did not permit this to be done, i.e., purposeless consumption of energy was suppressed.

TABLE 2

Summary of Effects of Changing Automotive Distillate Fuel and Gasoline Production at Two Levels of Fuel Oil Yield

	Automotive Distillate as % of Total Automotive Fuel*							
	10	19	28	37	46	55	64	73
• Process Energy Consumption as % of Total Energy Input								
Low fuel oil yield	9.1	8.8	7.9	7.4	7.2	7.3	7.7	9.7
High " " "	7.6	7.2	6.7	6.3	5.8	5.6	5.9	7.0
% Saving Relative to Base Case								
Low fuel oil yield	Base	0.3	1.2	1.7	1.9	1.8	1.4	-0.6
High " " "	Base	0.4	0.9	1.3	1.8	2.0	1.7	0.6
• Cost Savings in Cents/Million BTU of Total Automotive Fuel Product**								
Low fuel oil yield	Base	5	9	12	13$^{\phi}$	12	7	-5
High " " "	Base	3	6	8	10	10$^{\phi\phi}$	4	-6
• Investment Savings in Dollars/Million BTU Per Calendar Day of Total Automotive Fuel Product								
Low fuel oil yield	Base	22	48	69	83	83	53	-31
High " " "	Base	27	53	78	99	108	85	4

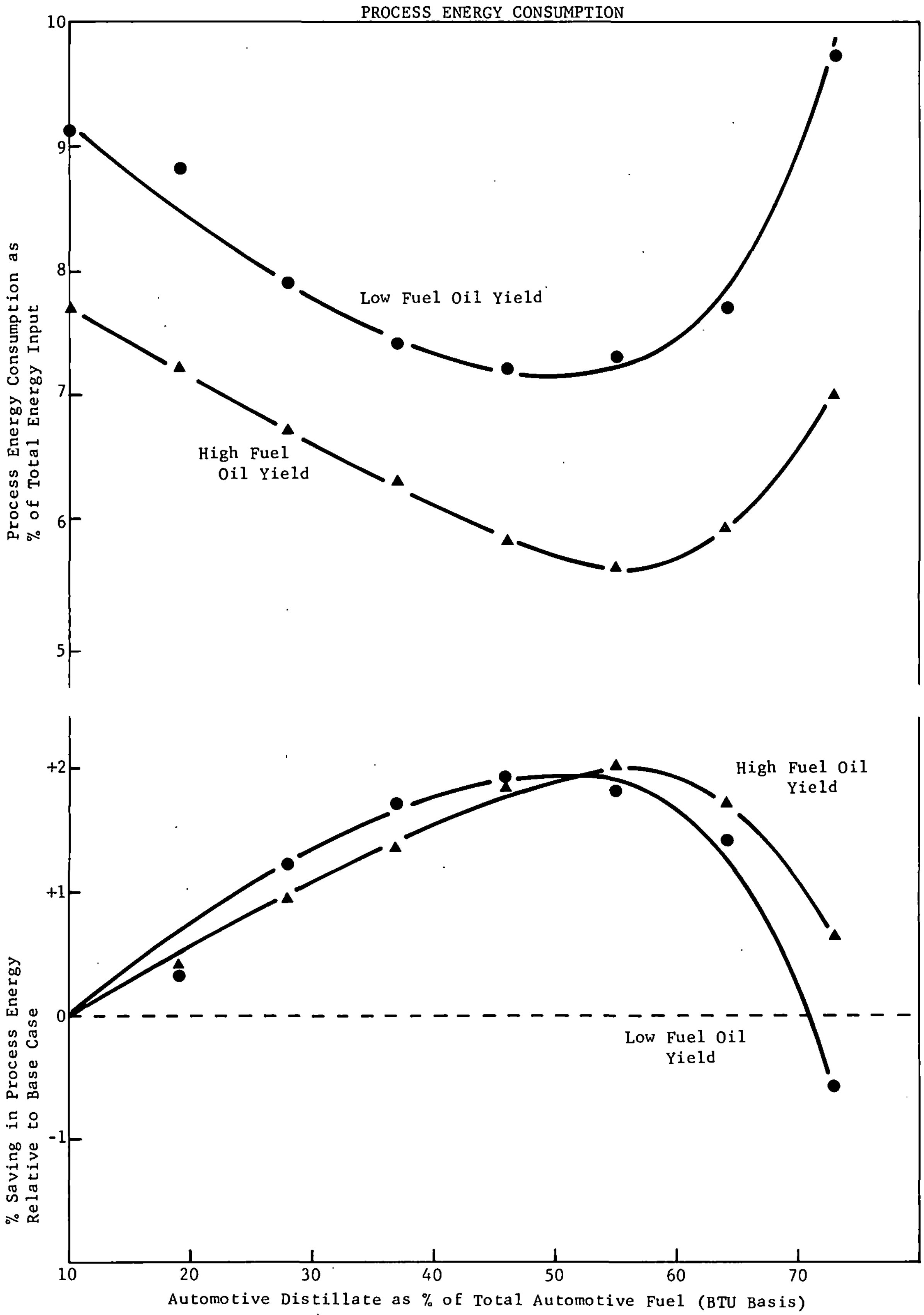
ϕ equivalent to 1.5 cents/gallon of total automotive fuel product
$\phi\phi$ " " 1.2 " " " " " " "

* on BTU basis, i.e., $\% = \frac{\text{(BTU's in Automotive Distillate Fuel)} \times 100}{\text{(BTU's in Automotive Dist. plus Gasoline)}}$

** Much of the cost saving is attributable to the lower investments required as the ratio of automotive distillate fuel to gasoline approaches unity. However, a lower crude oil requirement, for a given total output of automotive fuel, also contributes to a lower product cost. Additional explanation is provided in Appendix 2.

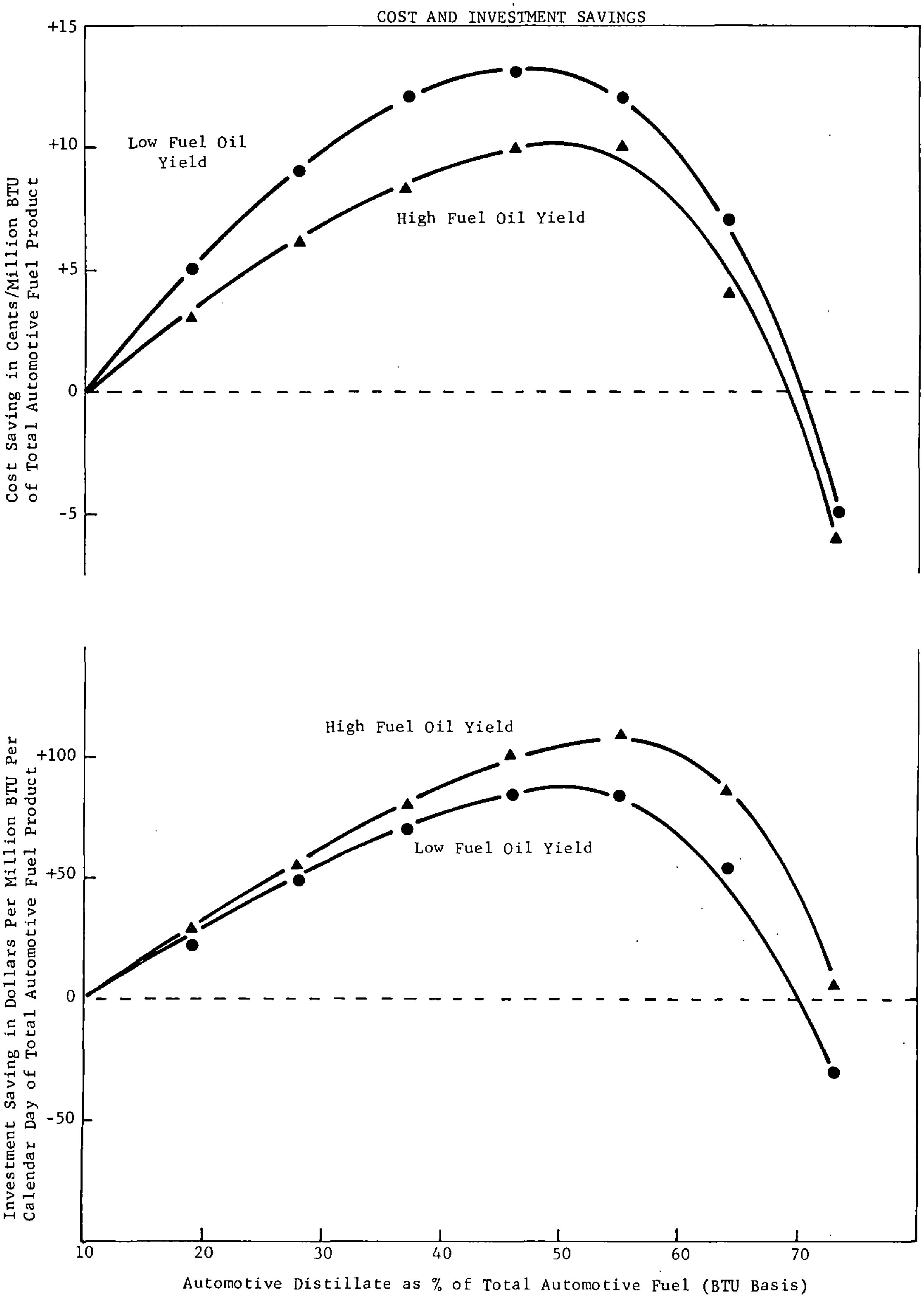
EPA-460/3-74-018

FIGURE 1



EPA-460/3-74-018

FIGURE 2



EPA-460/3-74-018

(7) Maximum cost savings were 13 cents per million BTU of total automotive fuel product in the low fuel oil yield case, and 10 cents per million BTU relative to the high fuel oil yield base case.* These savings approximate 1.5 and 1.3 cents/gal., respectively.

(8) Maximum investment savings were $83 and $108, respectively, per million BTU of daily capacity for producing automotive fuels.*

(9) The condition under which maximum savings were obtained corresponds to the point at which all atmospheric gas oil** is backed out of the feed to catalytic cracking. Thus, the optimum, but not the maximum, yield of automotive distillate occurs when none of the middle distillate occurring naturally in the crude oil is cracked. The maximum yield of automotive distillate occurs with considerable hydrocracking of vacuum gas oil.*** The respective cracking processes are discussed further in Section 4.5.

The reader is cautioned that the savings calculated to be obtainable by moving in the direction of equal quantities of automotive distillate and gasoline

(1) do not establish that the full extent of the move will be feasible--because of possible external constraints, such as those discussed in Section 5.

(2) do not establish that such a move is possible now, with the mix of domestic refining capacity currently in place.

4.3. Discussion of Results

The hypothetical savings are of a magnitude that would seem to warrant further study. For example, the current level of total product output by domestic refineries is a little under 14 MM B/D or about 5 billion barrels per year. At this level, a saving of 2% in process energy would be equivalent to 100 million barrels per year. With <u>imported</u> crude oil presently at about $10/bbl., the hypothetical saving would be at the level of $1 billion per year.

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* These estimates are based on a crude oil cost of $8/bbl. and an absolute level of investment of about $2,500 per daily barrel of crude charged. These values are representative of those reported in Report EPA-460/3-74-009 (see page 7 of Appendix 1 in Volume 3 and page 161 of Volume 2). The $83 and $108 figures do not take account of the production investment that is included implicitly in the assumed crude oil cost of $8/bbl. Directionally, a lower total requirement for petroleum would be expected to lower its future unit cost.

** i.e., virgin middle distillate from the atmospheric pipestill.

*** 650/1050°F distillate from the vacuum pipestill (i.e., not <u>middle</u> distillate).

The reader is cautioned that the hypothetical savings apply to a future refinery (or refining situation), and not to the mix of domestic refining capability currently in place. Furthermore, constraints external to the refining processes, may limit the savings to a (small) fraction of what is theoretically possible. Nevertheless, the cost/benefit ratio seems most favorable for a study that would resolve the externalities and also investigate the evolutionary path to whatever future systems' optimum is conceived.

The refining calculations do not attempt to quantify the additional savings that might accrue from being able to use distillate fuel in more efficient* automotive equipment. Such savings, and the means by which they may be effected, are outside the scope of the present study. However, the reader may be interested to know how the energy savings that are theoretically obtainable by changes in processing compare in magnitude with savings hypothetically obtainable through increasing the efficiency of automotive fuel use. Table 3 reports calculations that illustrate the relative magnitude of the two types of savings. In the example, the process energy saving is achieved by producing equal quantities of gasoline and automotive distillate fuel versus the base case in which the gasoline/automotive distillate ratio is 9:1. The fuel use savings are based on the arbitrary assumption that vehicles using distillate fuel could achieve an average of 15% better mileage than their gasoline-burning counterparts. With these assumptions, the fuel use saving is 1.5 times as large as the process energy saving. Not shown in Table 3, but easily calculated, is that the weight of the two types of savings would be the same if the average mileage advantage** for the automotive distillate/vehicle system were 10% relative to the gasoline/vehicle system.

Although the above example uses arbitrary assumptions, it suggests that energy savings will be possible if the commercial vehicle population is able to move (on an incremental basis) to a higher proportionate use of distillate fuel provided that the use of such fuel is significantly more efficient than the use of gasoline.

4.4. Additional Qualifications

In addition to the note of caution expressed at the end of Section 4.2, it is necessary to draw attention to other qualifications:

(1) The calculations pertain to comparisons of grass-roots refineries specifically designed for optimum processing of each gasoline/distillate demand case. Also, the grass-roots refineries are representative of an average U.S. situation rather than of a specific location.

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* relative to the efficiency of, or mileage obtainable by, future vehicles that use gasoline.

** per BTU of fuel consumed.

TABLE 3

Hypothetical Savings Relative to High Fuel Oil Yield Base Case of Producing Equal Quantities of Automotive Distillate and Gasoline, Combined with 15% Greater Efficiency in Distillate Fuel Use

• High Fuel Oil Yield Base Case	Relative Quantities on BTU Basis	Relative Mileage on BTU Basis
Energy input to refinery	108.2	-
Process energy consumption	8.2	-
Nonautomotive fuel products	48.9	-
Motor gasoline	$\left.\begin{matrix}46.0\\5.1\end{matrix}\right\}$ 51.1	100
Automotive distillate		115

Hence, total mileage:

by gasoline-powered vehicles	46 x 100 =	4600
" distillate-powered "	5.1 x 115 =	586.5
		5186.5 = (A)

• Equal Quantities of Automotive Distillate and Gasoline

Motor gasoline	25.55	100
Automotive distillate	25.55	115

Hence, total mileage:

by gasoline-powered vehicles	25.55 x 100 =	2555
" distillate-powered "	25.55 x 115 =	2938
		5493 = (B)

(1) If the required total mileage were (A) instead of (B), automotive fuel production could be reduced by 5.6%, i.e., (5493 - 5186.5) x 100 ÷ 5493, or from 51.1 to 48.2 units.

(2) Keeping the yield of other products the same at 48.9 units, the total required product output would be 48.2 + 48.9 = 97.1 units.

(3) Thus, the increased efficiency of automotive fuel usage would reduce the crude oil requirement by about 2.9%.

(4) In addition, refinery process energy requirements would be reduced by about 1.9% (see Figure 1; change is from 7.6% to 5.7%).

• Summary of Hypothetical Savings	Fraction of Total Saving
Due to greater efficiency of use item (3): 2.9%	0.4
Due to lower process energy requirement item (4): 1.9%	0.6
	1.0

EPA-460/3-74-018

(2) Quantitatively, the study is specific to the crude oil quality assumed.* The relationships could differ appreciably for synthetic crudes derived from coal or oil shale. In particular, such crudes are likely to contain a lower percentage of material boiling above middle distillate. This would limit the amount of higher boiling material potentially available for conversion to automotive fuels. In addition, the syncrudes, particularly from coal, may differ significantly from petroleum crudes in hydrocarbon-type composition thereby affecting the ease with which the specifications for individual products may be met.

(3) The effects of producing "petroleum specialties"** (e.g., lubes, asphalts, solvents) and petrochemical feedstocks were not investigated. Some of the specialties tend to be produced preferentially from certain crude oils via a mix of refining processes that could affect the optimum gasoline/distillate ratio calculated for a simple "fuel products refinery."

4.5. Discussion of Conversion Processes

Material in crude oil boiling above about 650°F is unsuitable for inclusion in distillate fuel. In current U.S. refining practice it is usual to convert vacuum distillate (approximately 650-1050°F fraction) to lower boiling fractions by catalytic cracking or hydrocracking. The former process produces a higher percentage of a good quality gasoline blendstock along with a smaller percentage of a (cracked) middle distillate. The catalytic cracking process has a limited capability for producing distillate selectively, i.e., for converting a heavier fraction to distillate without converting much of the feedstock to fractions boiling below distillate. In contrast, hydrocracking is able to achieve a greater degree of selectivity towards distillate. Thus, maximum (middle) distillate yields are associated with considerable usage of hydrocracking.

The relative merits and disadvantages of the two cracking processes depend, in part, on crude oil quality and on the product yield pattern desired. However, it should also be noted that hydrocracking:

(1) requires a higher investment than catalytic cracking (for a given throughput)

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* This point is elaborated in Appendix 2.

** Non-fuel petroleum products.

(2) requires hydrogen; consumption averages about 2000 SCF/bbl.*

(3) does not produce olefin by-products (as does catalytic cracking).

4.6. Automotive Wide-Cut

In addition to choice of processes discussed above, the maximum yield of automotive distillate fuel is achievable by controlling the distillation cut-point between naphtha and kerosene. The cut-point is chosen so as to maximize the production of the kerosene cut as limited by Flash Point specifications. In effect, some naphtha in the 310-360°F boiling range** may be diverted to, i.e., blended into, automotive distillate fuel. In the limit, the automotive distillate product is a type of wide-cut. Indeed, the distillate products in the right-hand columns of Table 2 are of this type.

Although the significance of Flash Point is an "externality," it is considered here rather than in Section 5 because of its direct impact on refinery processing conditions.

Currently, automotive diesel fuel is the only automotive distillate fuel in commercial use. The ASTM[3] makes the following observation about the Flash Point of automotive diesel fuel:

> "The flash point as specified is not directly related to engine performance. It is, however, of importance in connection with legal requirements and safety precautions involved in fuel handling and storage, and is normally specified to meet insurance and fire regulations."

The normal minimum Flash Point specifications for automotive diesel fuels are:

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* Hydrogen may be available as a by-product of catalytically reforming naphtha. However, this process is used primarily for the production of gasoline. Hence, if gasoline production is suppressed, the availability of by-product hydrogen will be reduced. When hydrogen is manufactured specifically, the operation will be reflected in additional investment for the hydrogen plant and in increased consumption of refinery process energy.

** The alternative disposition of this heavy naphtha fraction is to catalytic reforming to produce a high O.N. gasoline blendstock.

Grade	Description	Flash Point (min.)
1-D	A volatile distillate fuel oil for engines in service requiring frequent speed and load changes	100°F or legal*
2-D	A distillate fuel oil of lower volatility for engines in industrial and heavy mobile service	125°F or legal*

Similar ASTM specifications for (non-aviation) gas turbine fuels are:

Grade	Description	Flash Point (min.)
No. 1-GT	A volatile distillate for gas turbines requiring a fuel that burns cleaner than No. 2-GT	100°F or legal*
No. 2-GT	A distillate fuel of low ash and medium volatility suitable for gas turbines not requiring No. 1-GT	100°F or legal*

The blending of naphtha with the above grades of fuel would lower the Flash Point below the minimum specification. Besides the legal problem, such blending would also produce explosive mixtures. In the past, this difficulty has been experienced with wide-cut aviation fuels (JP-4 type), and has been one of the factors responsible for the preference now given by commercial airlines to kerosene-type fuels. A technical solution, which is applied to military aircraft that use JP-4 type fuels, is to use a specially designed safety tank for the fuel. It is unlikely that such an approach would be satisfactory for general automotive use.

Another way around the explosivity problem would be to blend sufficient butane** into the automotive fuel such that the resulting vapor pressure of the blend would keep it above the upper limit of explosivity. Vapor pressure varies with temperature and, from the standpoint of staying above the upper limit of explosivity, would present the greatest problem at low ambient temperatures. Thus, while a minimum Reid Vapor Pressure specification of 5 p.s.i. would give protection at an ambient temperature of about 35°F, it would be

* "Legal" implies that some authorities may require a higher minimum value than set by the normal specification.

** The explosive limits for butane are 1.8 to 8.4 mol.% in air.

necessary to blend to a minimum of 10 p.s.i. to protect at 0°F. In practice, this would mean that the wide-cut fuel would have to have RVP specifications approximating those of motor gasoline. This would render the fuel unsuitable for use by the present vehicle population that uses automotive distillate fuel (i.e., automotive diesel fuel). It is recognized that diesel engines can be modified to operate on high vapor pressure fuels. The point here is that the existing population of diesel-engine vehicles:

(1) Would not be able to operate on such fuels without significant, i.e., costly, modification.

(2) Would lose power through the necessary modifications.

(3) Would suffer a loss in terms of miles per gallon or miles per refuelling stop.

5. POSSIBLE EXTERNAL IMPLICATIONS

5.1. Heavy Ends Considerations

In aggregate, lubricating oils, petroleum waxes, petroleum coke, asphalt, and road oils account for about 8% of the current petroleum demand on a BTU basis. This is also the percentage of heavy fuel oil produced by domestic refineries. Historically, the U.S. has been an exporter of lubes and wax, some asphalt has been imported, while two-thirds of the heavy fuel oil consumed in recent years has been imported. It is beyond the scope of this study to forecast the future of such exports and imports. Nevertheless, it is clear that the U.S. will continue to have a need for the above "heavy ends" products in addition to fuel oil. Moreover, even if the latter product is eventually displaced from electricity base load generation, a continuing demand is expected for fuel oil in other end-uses (e.g., general industrial, some commercial sector uses, and marine bunker fuel). Thus, the complete conversion of the bottom of the petroleum barrel into lighter products does not appear to be a reasonable scenario. For the purposes of this study, it is guesstimated that the practical minimum yield of heavy products from domestic refineries will be about 8%. Considerable further study would be needed to get a better estimate of the minimum. It should be noted that the minimum is not determined by what is technically possible in petroleum refining but by the demand for certain types of petroleum products. To the extent that this demand can be satisfied economically by other means, it would be possible to achieve a higher level of conversion to lighter products.

Hypothetically, all "heavy ends" products could be imported. Such a scenario would be in conflict with the goals of "Project Independence." This, of course, does not mean that no heavy products will be imported in the 1990-2000 time-frame.

Conceivably, it would be possible to substitute synthetic lubes and waxes for the corresponding petroleum products. Indeed, some substitution has already occurred in special applications. However, it must be considered that the feedstocks for the synthetic materials are derived from petroleum, hence an across-the-board substitution would seem to be an inefficient use of available resources.

5.2. Naphtha as an Industrial Fuel

The conversion of "heavy ends" to lighter petroleum fractions cannot be restricted to conversion to middle distillate only; some lower boiling fractions, i.e., naphtha and gas, are produced also. Thus, a high level of conversion of heavy ends has the potential for causing different types of supply imbalance:

(1) insufficient fuel oil (because such a high proportion of heavy ends have been converted to lighter products);

(2) too much naphtha (since the postulated purpose is to increase automotive distillate at the expense of gasoline).

Consideration of (1) and (2) together leads to the theoretical possibility of using naphtha as a substitute for fuel oil. Technically, this is feasible, and is practiced on a small scale in Japan. Such a substitution requires equipment modifications and, thus, is best suited to large fuel consumers such as electric utilities. However, a key assumption in this study is that petroleum will be displaced from base load electricity generation in the 1990's. Therefore, the hypothetical use of naphtha would have to be by industry in general and by commercial users of fuel oil such as schools and hospitals. The practicality, safety, and economic implications of such use would require detailed study.

It must be remembered that, currently, the U.S. imports two-thirds of its heavy fuel oil. However, a number of projects to expand the fuel oil capability of domestic refineries are under way. It is not known whether this trend will continue, but it may be noted that the new plants that come on stream in the late 1970's should still be in operation in the 1990's. Hence, there is a conceptual conflict between (a) new investment in domestic capacity to produce low sulfur fuel oils, and (b) a postulate that naphtha can be substituted for fuel oil.

5.3. Syncrudes as Fuel Oils

The base contract, of which this study is an extension, examined the technical feasibility of producing alternative automotive fuels from coal and oil shale. However, it is not certain that coal and shale syncrudes will be utilized primarily for this purpose. It is possible that the syncrudes will be used primarily, or to a substantial extent, as low sulfur fuel oils. In concept, this would permit a greater utilization of petroleum for other purposes including automotive fuels. A conclusion reached in the base contract was that the ongoing studies should address the optimum utilization of all domestic resources including petroleum. The issue is that optimization of conventional petroleum refining is only a suboptimization unless considered in the context of the most effective use of all domestic resources.

One hypothesis that should be considered is that conventional crude oil production may peak in the 1990-2000 time-frame.* If so, and if considered in isolation from synthetic fuels, this would result in the peaking of petroleum refining capacity. On the other hand, an incremental supply of syncrudes could be integrated into petroleum refining. In this case, incremental refining investments would be designed to achieve a balanced product output for all purposes. This

* In fact, this is a widely held view with some projecting that the peak could come a little before 1990.

is consistent with the reasoning given in the report on the base contract, namely that availability of synthetics will be small in 1985 but could be a major factor in the total supply of liquid fuels by the year 2000. Nevertheless, considerable conventional petroleum is still likely to be available at this time.

5.4. Chemical Feedstock Considerations

This study can do little more than point out that a substantial shift in gasoline to distillate ratio could have a major impact on the petrochemical industry. A particular difficulty in discussing the matter is that the effects of such a shift in the 1990-2000 time-frame could be quite different from the impact of a hypothetical shift made today. The difficulty exists because petrochemicals can be, and are, derived from different raw materials. Today, the principal raw materials are:

(1) domestic natural gas;

(2) natural gas liquids, primarily of domestic origin;

(3) catalytic reformate from gasoline processing in domestic refineries;

(4) feedstocks obtained by steam cracking of petroleum liquids in domestic refineries;

(5) imported feedstocks or intermediates.

The future availability of natural gas and NGL will have a major impact on the quantity of petrochemical feedstocks that will have to be produced by domestic petroleum refineries. However, the future holds another major uncertainty, namely the extent to which petrochemicals or their precursors will be derived from synfuel operations, i.e., from coal and oil shale.

The lower throughput and lower severity of conversion processing associated with the production of more distillate and less gasoline would reduce the availability of light olefin by-products of catalytic cracking. The net effect on aromatic feedstocks is more complex. In principle, catalytic reforming could be used more to produce chemical aromatics and less to produce high O.N. gasoline blendstocks. However, the chemical demand for each of the C_6-C_8 aromatics differs appreciably (e.g., high chemical demand for benzene, toluene, and p-xylene but relatively low chemical demand for m-xylene and o-xylene). Correction of imbalances by isomerization and hydrodealkylation could involve considerable investment and consumption of process energy.

The current literature contains many projections that increasing quantities of chemical feedstocks will be derived from petroleum liquids. However, there are also projections that large volumes of chemicals will be derived from coal within the next 15 years. Thus, the practicality of simple "fuel products" refineries in the 1990-2000 decade is questionable.

The chemical industry is extremely important to the U.S. economy. Moreover, it has a larger investment in place than does petroleum refining. Much of the chemical industry is dependent on the petroleum industry for feedstocks. Hence it would be unwise to become committed to any major change in petroleum refining (such as a major shift in gasoline to distillate ratio) without first evaluating the possible impacts on the chemical industry. This task will be complex and difficult. It should also be noted that the automotive industry has a significant and growing requirement for petrochemical products, and that the use of such products is one route to reducing vehicle weight thereby improving mileage. Even automobile tires have a large petrochemical content.

5.5. Case Study and "No Surprise" Scenario for 1990

A recent case study of energy in the state of Oklahoma[4] contains projections that are pertinent to the present study. In particular, the report shows how automotive distillate fuel consumption may increase relative to gasoline consumption in the absence of any new external stimulus. The projections for Oklahoma may be converted into a "no surprise" 1990 scenario for the U.S. Several implications may be drawn from this scenario.

The Oklahoman demand for transportation energy is covered in Table 4. The data for 1974 are generally similar to those for the entire U.S. reported in Table 7 of Appendix 1. The principal differences are a proportionately higher demand for truck fuels in Oklahoma, accompanied by relatively lower demands for aviation and railroad fuels. In addition, the 1990 projections for Oklahoma show a marked increase in the demand for bunker fuel by barges.

Highway fuel demand is reported in Table 5. Here, it will be seen that buses have an insignificant impact on automotive fuel demand in Oklahoma. It will also be seen that the ratio of gasoline to distillate fuel use is expected to decline from 16.2 this year to 8.9 in 1990.

The end-uses of distillate fuels in Oklahoma are considered in Table 6. Comparison with Table 6 of Appendix 1 shows that distillate uses in Oklahoma vary considerably from the U.S. average. Three significant points follow:

(1) Residential demand for heating oil is the leading use for distillate in the U.S., but is at a zero level in Oklahoma (because of the availability of natural gas).

(2) Agricultural demand is not specifically covered in Appendix 1*, but is of outstanding importance in Oklahoma.

* It is probably divided among "Industrial," "Kerosene," and "Automotive Diesel," and will be at a low absolute level.

TABLE 4

Projections of Transportation Energy Demand in Oklahoma

	10^9 BTU				% of Total			
	1974	1980	1985	1990	1974	1980	1985	1990
Air - Gasoline	572	693	346	110				
- Jet	18048	21441	24426	27140				
Subtotal	18620	22134	24772	27250	8.6	8.5	8.5	8.4
Auto - Gasoline	128817	150420	164220	178020	59.6	57.9	56.3	54.8
Bus - Gasoline	135	161	182	202				
- Distillate	186	269	370	471				
Subtotal	321	430	552	673	0.2	0.2	0.2	0.2
R.R. - Distillate	2310	2940	3461	3996	1.1	1.1	1.2	1.2
- Electricity	1193	1778	2507	3236	0.5	0.7	0.8	1.0
Subtotal	3503	4718	5968	7232	1.6	1.8	2.0	2.2
Barges - Distillate	794	1818	3146	4473	0.4	0.7	1.1	1.4
- Bunker	4720	10722	18079	25347	2.2	4.1	6.2	7.8
Subtotal	5514	12540	21225	29820	2.6	4.8	7.3	9.2
Trucks - Gasoline	48574	53976	54608	55984	22.5	20.8	18.7	17.2
- Distillate	10742	15679	20206	25723	4.9	6.0	7.0	8.0
Subtotal	59316	69655	74814	81707	27.4	26.8	25.7	25.2
Total	216091	259897	291551	324702	100	100	100	100

Source: Reference (4); Vol. 2, Table 1-9, p. 18.

EPA-460/3-74-018

TABLE 5

Projections of Highway Fuel Demand in Oklahoma

	10^9 BTU				% of Total			
	1974	1980	1985	1990	1974	1980	1985	1990
Gasoline								
Autos	128817	150420	164220	178020	68.3	68.2	68.6	68.3
Trucks	48574	53976	54608	55984	25.8	24.5	22.8	21.5
Buses	135	161	182	202	0.1	0.1	0.1	0.1
Subtotal	177526	204557	219010	234206	94.2	92.8	91.5	89.9
Distillate								
Trucks	10742	15679	20206	25723	5.7	7.1	8.4	9.9
Buses	186	269	370	471	0.1	0.1	0.1	0.2
Subtotal	10928	15948	20576	26194	5.8	7.2	8.5	10.1
Ratio of Gasoline to Distillate	16.2	12.8	10.6	8.9				
Highway fuel as % of Oklahoma's total primary energy demand	20.2	17.1	14.8	13.4				

Source: Table 4

EPA-460/3-74-018

TABLE 6

Projected End-Uses of Distillate Fuel in Oklahoma

	10^9 BTU			% of Total		
	1970	1980	1990	1970	1980	1990
Stone, glass, clay	206	287	376			
Primary metals	298	-	-			
Food	120	167	218			
Wood & wood products	73	102	133			
Fabricated metals	545	760	993			
Other industrial	4674	6522	7193			
	5916	7838	8913	19.1	13.0	10.6
Electricity generation	244	8000	6400	0.8	13.3	7.6
Chemicals	1390	1937	2532	4.5	3.2	3.0
Residential	Nil	Nil	Nil	-	-	-
Misc. commercial	4181	5833	7623	13.5	9.7	9.1
Agricultural	4337	15845	23867	14.0	26.3	28.4
Bus	131	269	471			
Truck	10584	15679	25723			
	10715	15948	26194	34.7	26.6	31.2
Barge	160	1818	4473			
Rail	3969	2940	3996			
	4129	4758	8469	13.4	7.9	10.1
Total	30912	60159	83998	100	100	100

Source: Reference (4); Vol. 2, page 37 et seq.

EPA-460/3-74-018

(3) The post-1980 decline in distillate fuel requirements by Oklahoma's electric utilities is attributable to a rapid expansion projected for the use of coal.

For Oklahoma, the implied development and increasing mechanization of the state's agriculture is probably the single most significant point. If this projection is valid for Oklahoma, then it is probably valid for other agricultural states in the Corn and Wheat Belts. One implication is that (off-highway) agricultural demand for automotive distillate fuels is worth consideration.

Based largely on the Oklahoma case study, it is possible to construct a "no surprise" 1990 scenario for the entire U.S. Its principal elements are:

(1) Slowdown in the growth rate for distillate fuel demand by general industry.

(2) Downturn, probably post-1985, in electric utility demand for distillate fuel.

(3) Eventual reversal, possibly before 1980, in the demand for home heating oil (this depends primarily on national policy with respect to natural gas).

(4) Increase in off-highway uses of distillate fuel by railroads, barges, construction/mining equipment, and agricultural vehicles.

(5) Further shift of commercial highway vehicles to distillate fuels.

(6) No significant use of distillate fuel in automobiles, excluding taxis.

In this scenario the level of automotive distillate fuel consumption (highway plus off-highway) could be 2 to 3 times what has been projected for 1974. Reference to Figure 1 suggests that such a development would permit about one-third to as much as one-half of the theoretical maximum savings in process energy to be achieved. This scenario appears compatible with prudent refining practices for both petroleum and synthetic fuels. The trends covered in items (1) through (6) could continue through the year 2000. A downturn in distillate fuel consumption by general industry may be hypothesized between 1990 and 2000.

It is recognized that much of the above is speculation, and is not adequately supported by the present study. The purposes of the speculation are to suggest directions for additional study and to indicate the type of results that might be obtained.

In support of item (6), the "no surprise" scenario hypothesizes that the current trend to smaller cars will continue, and that this trend will be a major factor in the future conservation of automotive fuels. The hypothesis leads towards a question that cannot be answered by this study, but may be of major importance, namely: Will it be feasible to produce small cars of acceptable performance and "driveability" that are powered by engines able to burn distillate fuel? If the practical answer to this question should be "No," then the conservation options would include:

- use of distillate fuel by commercial and off-highway vehicles;

- possible use of distillate fuel by largers cars and taxis;

- use of gasoline by small cars.

It should be noted that the refining cases discussed in Section 4 showed an internal* optimum when approximately equal quantities of automotive distillate and gasoline were produced. An external implication is that the overall optimum** may require a vehicle population comprising some vehicles that use gasoline and others that use distillate fuel. This does not mean that today's situation is optimal, since the relative proportions of the two types of vehicles may not be optimal. However, it does suggest that an "all distillate fuel" scenario is not viable.

* Internal to the refinery.

** Which takes full account of all end-uses as well as refinery processing.

6. CONCLUSIONS

This section is divided into two parts. The first set of conclusions concerns refinery processing and is claimed to be valid only within the context of the assumptions upon which the calculations are based. These conclusions may have a more general validity, but this is not known. The second set of conclusions is, more precisely, a listing of several key questions that should be answered before the refining conclusions may be credited with broader validity.

Refinery Processing

(1) Relative to base cases that represent current production and consumption of automotive fuels in the U.S., it is theoretically possible to make significant savings by increasing the production of automotive distillate fuel with a corresponding decrease in gasoline production.

(2) The savings apply to new refining capacity that is conceived to come on stream in the 1990-2000 time-frame. The quantitative savings do not apply to existing petroleum refineries.

(3) Maximum savings occur when approximately equal quantities of automotive distillate fuel and gasoline are produced. The calculated savings are:

  (a) In process energy: equivalent to about 2% of the crude oil charged.

  (b) In refining investment: $83 per million BTU/CD of total automotive fuel product in the low fuel oil case, or $108 per million BTU/CD with a higher yield of fuel oil.

  (c) In the cost of the automotive fuels produced: 13 cents/million BTU (or about 1.5 cents/gal.) if the refinery makes a low yield of heavy fuel oil, or 10 cents/million BTU (or about 1.3 cents/gal.) with a higher yield of heavy fuel oil. Item (c) is the consequence of (a) and (b).

(4) The condition for maximum savings occurs when all atmospheric gas oil (i.e., virgin* middle distillate from the atmospheric pipestill) is backed out of the feed to catalytic cracking.

(5) With total U.S. crude runs of 14 MM B/D, the theoretical process energy saving is 100 million barrels per year. Based on backing out imported crude oil at about $10/bbl., the hypothetical saving would be $1 billion annually.

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* "straight run" or not cracked, i.e., the middle distillate that is present in the crude oil.

(6) Further study would be required to determine how much of the hypothetical saving is feasible. The cost/benefit ratio for such a study appears most favorable.

External Considerations

(7) Petroleum refineries must meet the demand for many types of products, not just automotive fuels. Such requirements may limit the extent to which the proportions of automotive distillate and gasoline can be varied.

(8) Syncrudes derived from coal or oil shale are likely to contain a lower percentage of material boiling above middle distillate. This would limit the amount of higher boiling material potentially available for conversion to automotive fuels. Directionally, the processing "optimum" for maximum savings is expected to be at a distillate/gasoline ratio closer to 1:2 rather than to the 1:1 ratio calculated for conventional crude oils.

(9) Changes in refinery processing could have a major impact on the availability of chemical feedstocks. Thus, it would be unwise to become committed to any major change in refining practice without first evaluating the possible impacts on the chemical industry. The automotive industry has a significant and growing requirement for petrochemical products, and the use of such products is one of the means by which vehicle weight may be reduced and mileage improved.

(10) Elimination of the production of gasoline appears neither optimum nor feasible. The implication is an automotive population comprising some vehicles that use gasoline and others that use distillate fuel. One such possibility is:

(a) use of distillate fuel by commercial and off-highway vehicles;

(b) use of distillate fuel by taxis and, perhaps, some large cars;

(c) use of gasoline by small cars.

7. REFERENCES

Sections 1-6

(1) "Energy/Environmental Factors in Transportation 1975/1990," Mitre Corporation, Report MTR-6391, April 1973.

(2) Annual Petroleum Statement, Mineral Industry Surveys, U.S. Bureau of Mines.

(3) 1973 Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, Pa. Pertinent material may be found on:

(a) pages 163-167, relating to the standard specification for fuel oils: D396-73;

(b) pages 325-328, relating to the standard specification for diesel fuel oils: D975-73;

(c) pages 1053-1057, relating to the standard specification for gas turbine fuel oils (excepting aviation turbine fuels): D2880-71.

(4) "Energy in Oklahoma," final report of the Oklahoma Energy Advisory Council, February 1, 1974 (2 volumes).

Appendices

(5) Oil and Gas Journal, May 13, 1974, pages 30-31.

(6) "U.S. Energy through the Year 2000," W. O. Dupree and J. A. West, U.S. Department of the Interior, December 1972.

(7) Oil and Gas Journal, December 3, 1973, page 15.

APPENDIX 1

DISCUSSION OF U. S. PETROLEUM REFINING IN 1974

For a given quantity of crude oil, it is easy to conceptualize that more gasoline may be made at the expense of distillate fuel, or vice versa. However, many other products are also derived from crude oil, and their production could be affected by changes in the gasoline/distillate ratio, or could limit the extent to which it is feasible to change the ratio. Projections of U.S. petroleum supply/demand for the current year* are used to illustrate the more important factors that increase or limit the flexibility of changing gasoline/distillate ratio.

(1) Seasonal Demand

The demand for individual petroleum products varies throughout the year. Seasonal variations are particularly marked for motor gasoline and middle distillates, which have mutually "counterseasonal" peaks as shown in Table 1 of this Appendix.

The balancing of demand for individual products is achieved by a combination of:

(a) processing flexibility in individual refineries (e.g., variation in the ratio of mogas to distillate);

(b) seasonal storage (e.g., the build-up of inventories of distillate during the summer in anticipation of peak demand during the winter);

(c) product imports.

Without such balancing mechanisms, it would be necessary to have more refining capacity in order to satisfy the seasonal peaks in demand for individual products. Thus, the average level of capacity utilization would be lower. The effect would be to increase the total investment in petroleum refining without increasing the annual output of petroleum products. Hence, the unit costs of the products would be increased.

* Reference (5). The statistics quoted were prepared by the Supply and Demand Committee of the Independent Petroleum Association of America (IPAA). The numerical precision of IPAA's estimates is of small consequence to the present study since they are used solely for illustrative purposes.

A scenario for the future involving less petroleum imports and a lessening importance of heating oil implies less opportunity for balancing variations in seasonal demand by mechanisms (a) and (c). Presumably, balance would have to be achieved by a higher level of seasonal storage combined with a lower level of average capacity utilization, thereby raising overall costs to some extent. Thus, the estimated savings discussed in Section 4 could be offset somewhat, on an absolute basis, by seasonal costs. However, the estimated savings relative to the base cases should remain valid.

(2) Domestic Production

The projected imports of mogas and middle distillates are:

	MB/D in 1974				
	1-Q	2-Q	3-Q	4-Q	Year Av.
Mogas	183	192	206	203	196
Mid-Dist.	369	281	291	415	339
	552	473	497	618	535

The above quantities may be deducted from the total domestic demand statistics in Table 1 in order to derive what domestic production will have to be in order to satisfy the supply/demand balance* in 1974:

	Production by U.S. Refineries**, MB/D				
	1-Q	2-Q	3-Q	4-Q	Year Av.
Mogas	5756	6571	6819	6657	6426
Mid-Dist.	3560	2528	2356	3507	2961
	9316	9099	9175	10064	9387

Thus, the percentage swings for domestic production are even greater than for domestic demand. However, the reverse is true for the combination of mogas plus distillate. One inference is that domestic refineries must have the processing flexibility to vary the ratio of mogas to distillate production. On a quarterly basis the required 1974 ratios are:

	Ratio of Mogas to Distillate				
Basis	1-Q	2-Q	3-Q	4-Q	Year Av.
Domestic Demand	1.51	2.49	2.65	1.72	2.00
Domestic Production	1.62	2.60	2.89	1.87	2.17

* For simplicity, the effect of stock changes is ignored. In fact, IPAA's projections involve a modest rebuilding of the stocks of some products.

** Including manufacture of products from imported crude oil.

The implication is that while refineries may be designed with some optimum ratio in mind, it will not be possible to operate the refineries continuously at the theoretical optimum. Hence, the practical savings achievable will be somewhat less than the maximum reported in Section 4. This does not invalidate any of the broad conclusions drawn in Sections 4 and 6. However, it does mean that the focus should be on these broad conclusions rather than on the exact numerical savings calculated.

(3) Interaction with Aviation Fuels

Aviation fuels may be divided into two types:

(a) aviation turbo fuel, which accounts for about 96% of total aviation fuel demand

(b) aviation gasoline, which accounts for the remaining 4% of demand.

The turbo fuel, essentially kerosene with specific quality requirements, is actually a distillate fuel although it is excluded from most statistics for "middle distillates." Analogously, aviation gasoline is essentially a variant of motor gasoline from the standpoint of refining operations. However, aviation turbo fuels are a very significant factor in the total demand for distillate fuels while aviation gasoline is a minor factor in the total demand for gasoline.

The U.S. demand for aviation fuels in 1974 is projected to be:

	MB/D				
	1-Q	2-Q	3-Q	4-Q	Year Average
Total Av. Fuel	991	1058	1093	1117	1065
• Turbo Fuel	951	1016	1049	1072	1022
• Avgas	40	42	44	45	43
% Imported	14.3	16.1	17.0	18.1	16.4

When imports are subtracted from domestic demand, the implied domestic production becomes:

	MB/D				
	1-Q	2-Q	3-Q	4-Q	Year Average
Total Av. Fuel	849	888	907	915	890
• Turbo Fuel	815	852	871	878	854
• Avgas	34	36	36	37	36

The gasoline/distillate ratio may now be reconsidered after inclusion of the respective types of aviation fuel:

Ratio of Gasoline to Distillate				
1-Q	2-Q	3-Q	4-Q	Year Average
1.32	1.95	2.12	1.50	1.69

Thus, on a quarterly domestic production basis, the ratio of Mogas-plus-Avgas to Distillate-plus-Turbo fuel is projected to range from 1.3 to 2.1. Although seasonal storage will reduce the operating range required in refineries, it is clear that considerable processing flexibility to vary the gasoline/distillate ratio is necessary. This is an elaboration of points discussed at the end of the preceding section. It does not affect any of the broad conclusions drawn in the body of the report.

(4) Effect of Imports

Projections of petroleum imports are given in Table 2. Several points are worth noting:

(a) a steadily increasing dependence on petroleum imports is projected, rising to almost 40% of total supply in the last quarter of 1974

(b) imports of mogas represent a small fraction (about 3%) of domestic demand

(c) imports of aviation fuels and middle distillates are at higher percentage levels than mogas

(d) imports of heavy fuels are very significant indeed, accounting for a full two-thirds of domestic demand (and an even greater fraction of the total supply of low sulfur fuel oils).

It is important to understand the significance of item (d). Without imports of fuel oil, it would be necessary (currently) to make drastic changes in the product slate of domestic refineries in the direction of increasing fuel oil production at the expense of mogas, distillate, and other products. Currently, however, it would not be possible to match the low sulfur content of imported fuel oils with domestic production. The relationships among gasoline/distillate ratio, hydrogen availability, and product sulfur content are discussed in the introduction to Appendix 2.

It is also important to understand the extent to which the product pattern of oil imports complements the domestic yield pattern. Pertinent statistics are shown in Table 3. One aspect of the difference in yield patterns involves gasoline/distillate ratios:

Ratio	Domestic Production	Imports	Domestic Demand
Mogas/Distillate	2.17	0.58	2.01
Mogas-plus-Avgas to Dist. + Turbo Fuel	1.69	0.40	1.54

Without imports, the gasoline/distillate ratio produced by domestic refineries would have to be decreased--but this would not increase the availability of distillate for automotive uses. The explanation of this superficial anomaly is that total production of automotive fuels would have to be reduced in order to satisfy essential demands for other petroleum products.

(5) Competing End-use Demand

U.S. demand for petroleum products is projected to average 17.1 MB/D* in 1974. A plausible breakdown of this demand by principal end-uses is given in Table 4. The purpose is to allow the demand for gasoline and distillate products to be:

(a) related to individual end-uses

(b) seen in the broader context of demand for all types of petroleum products.

The estimates for the naphtha-type products are reviewed again in Table 5. It will be seen that mogas is the dominant product and that, in aggregate, naphtha-type products are expected to account for 40% of total petroleum demand in 1974.

A comparable review of distillate products is given in Table 6. The diversity of end-use is much greater. Of special note is that automotive diesel fuel accounts for only one-eighth of the total, and has only half the weighting of aviation turbo fuel.

A summary of transportation fuel demand projections is given in Table 7. The dominance of highway fuel demand and the contribution to this demand made by passenger cars should be noted.

(6) Comparison with D.O.I. Projections

The projections of petroleum demand for 1974 made by the IPAA may be compared with the Department of the Interior's forecast published in December 1972(6). By interpolation between 1971 and 1975, the D.O.I.'s forecast of transportation fuel for 1974 was 9000 MB/D, or 1.5% more than IPAA's projection. The agreement is close when allowance is made for the abnormal supply conditions in the first quarter of the year.

* Million barrels per day.

D.O.I.'s forecast for total petroleum demand was an average of 16.8 MB/D in 1974, or 2% less than the IPAA's projection. Thus, the more recent IPAA study suggests that petroleum demand for nontransportation uses has been increasing more rapidly than forecast by D.O.I., while transportation demand has been increasing somewhat less rapidly. It is not clear whether this divergent trend has long range significance or is merely a transient aberration. Resolution of the issue is beyond the scope of this brief study. However, the issue itself is important because:

(a) substitution of nonpetroleum energy (e.g., coal, nuclear power) for petroleum is potentially easier in stationary than in transportation uses;

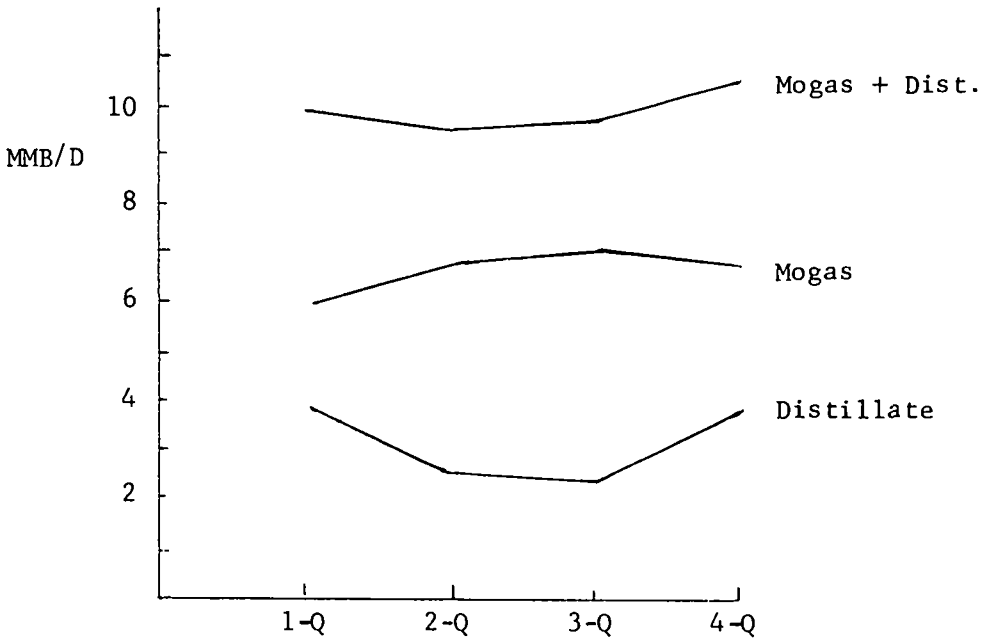
(b) the feasibility of making significant increases in the availability of automotive distillate fuel depends on limitation of demand for nonautomotive purposes (assuming a given level of total petroleum supply).

Appendix 1

TABLE 1

Seasonal Demand for Motor Gasoline and Middle Distillate Projected for 1974

	MB/D				
	1-Q	2-Q	3-Q	4-Q	Year Av.
Mogas	5939	6763	7025	6760	6625
Mid-Dist.	3929	2709	2647	3922	3300
	9868	9472	9672	10682	9925



Source: Reference (5)

EPA-460/3-74-018

Appendix 1

TABLE 2

Projections of Petroleum Imports
as a Percentage of Total U.S. Demand in 1974

	1-Q	2-Q	3-Q	4-Q	Year Av.
Crude oil*	18.3	21.8	24.7	25.9	22.8
Mogas	3.1	2.8	2.9	3.0	3.0
Av. fuels	14.3	16.1	17.0	18.1	16.4
Mid-Dist.	9.4	10.4	11.0	13.8	10.3
Heavy fuels	62.0	67.7	70.0	65.0	66.1
Liquefied gases	10.9	9.2	9.8	10.3	10.1
Other	18.3	16.7	16.1	17.1	17.0
Crude + Products	32.9	35.0	37.6	39.6	36.4

* Domestically produced natural gas liquids (NGL) are included with domestic production of crude oil, i.e., the above figure is the percentage that imported crude oil represents of the total of imported crude + domestic crude + domestic NGL.

Source: Reference (5)

EPA-460/3-74-018

Appendix 1

TABLE 3

Projected Yield Pattern for Domestic Production, Imports, and Total Domestic Petroleum Demand in 1974

Volume Basis, MB/D	Domestic Production	Imports	Domestic Demand
Mogas	6429	196	6625
Av. fuels	890	175	1065
Mid-dist.	2961	339	3300
Heavy fuels	922	1794	2716
Liq. gases	1333	150	1483
Other	1619	331	1950
	14154	2985	17139
Mogas + Avgas	6465	203	6668
Dist. + Turbo	3815	507	4322
Percentage Basis			
Mogas	45.4	6.6	38.6
Av. fuels	6.3	5.9	6.2
Mid-dist.	20.9	11.3	19.3
Heavy fuels	6.5	60.1	15.8
Liq. gases	9.4	5.0	8.7
Other	11.5	11.1	11.4
	100	100	100
Mogas + Avgas	45.7	6.8	38.9
Dist. + Turbo	26.9	17.0	25.2

Source: Reference (5)

EPA-460/3-74-018

Appendix 1

TABLE 4

Breakdown of Projected 1974
Petroleum Demand by End-Use, MB/D

	Boiling Range					
	Gas Liquids	Naphtha	Distillate	Heavy Fuels	Not Allocated	Total
Motor Gasoline						
Cars		4885				
Trucks/Buses		1510				
Other		230				
		6625				6625
Aviation Fuels		42	1023			1065
Distillates						
Kerosene			230			
Heating oils			1525			
Electric Utils.			275			
Industrial			370			
Auto diesel			540			
R.R. "			270			
Marine "			90			
			3300			3300
Heavy Fuels						
Electric utils.				1510		
Industrial/Other				926		
Marine bunker				280		
				2716		2716
Liquefied Gases	1483					1483
Other						
Lubes/Wax/Coke/Asphalt/Road oil				1170		1950
Miscellaneous*	50	200	100		430	
	1533	6867	4423	3886	430	17139

* Including feedstocks; breakdown by boiling range is very approximate.

Source: Contractor's own estimates in conjunction with Reference (5)

Appendix 1

TABLE 5

Breakdown of Projected End-Use of Naphtha-Type Products

	1974 Av. MB/D	% of Mogas	% of Naphtha	% of Total Petroleum
Mogas				
Cars	4885	73.7	71.1	28.5
Trucks/Buses	1510	22.8	22.0	8.8
Other	230	3.5	3.4	1.3
	6625	100	96.5	38.7
Avgas	42	-	0.6	0.2
Miscellaneous*	200	-	2.9	1.2
	6867	-	100	40.1

* Includes feedstocks for SNG and petro-chemicals, but estimate is very approximate.

Source: Contractor's own estimates in conjunction with Reference (5)

Appendix 1

TABLE 6

Breakdown of Projected End-Use of Distillate Products

	1974 Av. MB/D	% of "Dist. Fuel"	% of Mid-Dist.	% of Total Petroleum
"Distillate Fuels"				
Heating oils	1525	49.7	34.5	8.9
Electric utils.	275	9.0	6.2	1.6
Industrial	370	12.0	8.4	2.1
Automotive diesel	540	17.6	12.2	3.2
R.R. "	270	8.8	6.1	1.6
Marine "	90	2.9	2.0	0.5
	3070	100	69.4	17.9
Kerosene	230	-	5.2	1.3
Av. turbo fuel	1023	-	23.1	6.0
Miscellaneous*	100	-	2.3	0.6
	4423	-	100	25.8

* Very approximate.

Source: Contractor's own estimates in conjunction with Reference (5)

EPA-460/3-74-018

Appendix 1

TABLE 7

Summary of Transportation Fuel Demand*

	% of Total
Highway**	80.8[ø]
Aviation	12.0
Railroad	3.0
Marine	4.2
	100

ø 59.5% out of the 80.8% is for automobiles

Product Type	End-Use	MB/D	%
Naphtha	Mogas	6625	74.7
	Avgas	42	0.5
		6667	75.2
Distillate	Highway diesel	540	6.1
	R.R. "	270	3.1
	Marine "	90	1.0
	Aviation turbo	1023	11.5
		1923	21.7
Fuel oil	Marine bunker	280	3.1
Total		8870	100

* Petroleum only. Excludes electricity and natural gas.

** Includes off-highway uses in agriculture and construction.

Notes: "Imported" fuels sold in bond to aircraft and vessels are excluded.

Military fuel requirements supplied domestically are included.

Source: Tables 5 and 6 of this Appendix

APPENDIX 2

BASES FOR PETROLEUM REFINING CALCULATIONS

Introduction

Qualitatively, U.S. refineries can produce more distillate at the expense of gasoline. However, there is disagreement on what is feasible quantitatively. The following quotation[7] states the issue:

> "U.S. refiners are split from one extreme to the other as to whether they can cut gasoline production by 15% and raise middle distillate production by the same amount."

Beyond the normal seasonal variations in mogas/distillate ratio discussed in Appendix 1, a 15% swing would require changes to catalytic cracking operations. Lower severity would reduce the mogas/distillate ratio, but it would also reduce the output of LPG and light olefin feedstocks needed by the petrochemical industry. Theoretically, the olefins could be obtained by steam cracking naphtha. This would involve additional investment and a delay of about three years while the new plants were being constructed. In turn, this investment and call on skilled manpower might be expected to act as a brake on the development of synthetic fuel plants. Additionally, the incremental distillate produced at the lower mogas/distillate ratio would have a higher average sulfur content than current distillate fuels. Hence, additional desulfurization capacity would be needed, particularly if the distillates were intended for automotive use. However, much of the hydrogen needed for desulfurization is the by-product of gasoline processing (catalytic reforming). At a lower level of mogas production less, rather than more, by-product hydrogen would be available. In consequence, it would be necessary to undertake hydrogen manufacture from a feedstock such as naphtha*. Energy would be consumed in the additional processing (steam cracking, hydrogen manufacture, distillate desulfurization), but would be offset by lower energy consumption in other processes (catalytic cracking at lower severity, gasoline processing).

Currently, issues of this type are being studied by the Federal Energy Administration**. However, there is little doubt that <u>some</u> energy savings are possible through <u>some</u> increase in the use of automotive distillate fuel in place of gasoline. The flexibility for moving in this direction may

* Natural gas would be a preferred feedstock, but its availability is restricted. There would be a net inefficiency if gas diverted from other uses to hydrogen manufacture had to be replaced in such other uses by distillate fuel.

** "These studies have attempted to assess the impact on the refining industry of the reduction of lead in gasoline, the removal of sulfur in the refining process, and the <u>changes in gasoline/heating oil production capacity</u>," <u>Oil Daily</u>, 7/18/74.

be limited today. Thus, the calculations in this report are not valid for assessing the effects of changing the yields of automotive fuels in existing refineries. Nevertheless, process flexibility may be possible by 1990 provided that steps in this direction are begun well in advance of this time.

This Appendix describes the bases upon which refining calculations were made to explore the internal* effects of increasing automotive distillate production at the expense of gasoline. For simplicity, the differential cost of producing varying percentages of automotive distillate fuel was calculated. This was done without changing the yields of any of the nonautomotive fuel products except heavy fuel oil. Calculations were made for two different levels of fuel oil yield, as discussed in Section 4.1.

Crude Oil Quality

The cost of refinery processing, and its optimization for any given purpose, depends on crude oil quality. In general, the absolute cost is lower for lighter crudes of low sulfur content. In general, also, lighter crudes favor the production of naphtha-type fuels because the crudes contain a higher percentage of naphtha.

For the refining calculations, it was assumed that the average quality of crude oil processed in domestic refineries in the 1990-2000 time-frame would be:

A.P.I. Gravity	35.6°
Sulfur	0.65 wt.%
MM BTU/bbl. (LHV)	5.4

These qualities approximate, but are slightly higher than, the current average of domestic crude oil production. Conceptually, domestic production in the 1990-2000 will have a much heavier weighting of offshore and Alaskan crudes. The former tend to have high A.P.I. Gravity and low sulfur content. The latter exhibit considerable quality differences. However, the giant Prudhoe Bay field is medium in gravity and sulfur content. Hence, the average quality of future domestic crude oil may not be appreciably different from what it is today. The assumption of somewhat better quality crude in 1990-2000 with today's process technology is probably equivalent to assuming today's quality with some improvements in technology.

It should be noted that the average quality of crude oil run in domestic refineries is greatly influenced by the amount and type of crude oil imported. If "Project Independence" succeeds, this will not be a major factor in the 1990-2000 time-frame.

* internal to the refinery, without consideration of external impacts.

Product Specifications

A simplified product slate was used for the processing cost calculations. Besides LP gases, it was assumed that the following products would be made:

(1) motor gasoline

(2) aviation turbo fuel (kerosene-type)

(3) automotive distillate fuel

(4) other middle distillate

(5) fuel oil.

For the purposes of the study, it was also assumed that:

(a) mogas could be represented by a single grade, and that any avgas required would not affect the specifications of the gasoline pool

(b) all aviation turbo fuel would be kerosene-type, and that the demand for kerosene as heating oil would disappear

(c) automotive distillate fuel would meet minimum diesel fuel specifications

(d) the specifications for nonautomotive distillate fuel would be slightly less restrictive than (c)

(e) heavy ends products such as lubes/wax/asphalt/road oil could be included with fuel oil from the standpoint of yield on crude.

The pertinent product specifications are reported in Table 1. The specified qualities are believed to be at realistic levels, but may be somewhat lower in quality than will actually be required and produced in the 1990-2000 time-frame. While some product grades are likely to be higher in quality, a guiding consideration has been to avoid the assumption of restrictive specifications that would raise processing costs beyond what is clearly justified.

The fuel oil specification of 0.5 wt.% S requires special comment. It is intended to represent average fuel oil sulfur quality before the separation of asphalt (which lowers the S content of the deasphalted oil). It is also intended as a pool sulfur content, having in mind that the pool would be used to produce marine bunker fuel as well as low sulfur industrial fuel oil. By taking a middle path with respect to fuel oil sulfur, the cost calculations are not made hypersensitive to bottoms processing. The sensitivity to bottoms processing investments and costs would be magnified if the average quality of crude oil processed were inferior to that assumed in the preceding section.

Processes Employed

The calculations are based on the use of existing petroleum refining technology. No attempt was made to predict cost savings that may be possible through "learning curve" improvements or more radical changes in technology. However, hydrogen manufacture, desulfurization, and heavy ends processing appear to be areas in which improvements are both desirable and likely. Such improvements would make possible the running of somewhat lower average quality crude oil with less of a penalty that would apply currently.

The refining processes available to produce automotive fuels and other products from conventional crude oils are listed in Table 2. It will be recognized that many "downstream" processes, e.g., for manufacturing lube oils, are excluded because they have little direct impact on the gasoline/distillate fuel question. Provisions were made for offsites, utilities, and tankage to support the onsite process facilities. Plant fuel was generated within the refinery from gaseous and liquid streams.

Cost Basis

Costs and investments are in 1973 dollars, for consistency with the "Feasibility Study of Alternative Automotive Fuels."* However, it is possible that actual escalation of costs may be greater than in the economy as a whole, i.e., the constant dollar basis may not compensate completely for cost escalation in petroleum refining. The costs include a 10% DCF return, and assume an annual cost recovery factor of 0.215 of investment.

* 3-volume report EPA-460/3-74-009. See Appendix 7 in Volume 3 for details of DCF return and cost recovery factor.

Appendix 2

TABLE 1

Product Specifications

(a) Motor Gasoline

Reid Vapor Pressure, p.s.i.	10.5 (max.)
% at 160°F	24-33
" " 210°F	45-57
Research O.N.	84 (min.)
Motor "	92 (min.)

(b) Aviation Turbo Fuel

Luminometer No.	48 (min.)
Freeze Pt., °F	-40 (max.)
Sulfur, wt.%	0.2 (max.)

(c) Automotive Distillate Fuel*

Flash Pt., °F	125 (min.)
% at 450°F	10 (min.)
" " 662°F	97 (min.)
Cloud Pt., °F	10 (max.)
Cetane Index	45 (min.)
Sulfur, wt.%	0.1 (max.)

(d) Other Middle Distillate

A.P.I. Gravity, degrees	28 (min.)
% at 450°F	15 (min.)
Sulfur, wt.%	0.1 (max.)

(e) Fuel Oil

Viscosity, SSF at 122°F	175 (max.)
Sulfur, wt.%	0.5 (max.)

* Satisfactory for use in current automotive diesel engines.

Note: All burner fuels will meet appropriate Flash Point specifications.

Appendix 2

TABLE 2

Refining Processes Available

Primary Distillation

Atmospheric pipestill
Vacuum "
Light ends fractionation

Hydrofining

Naphtha hydrofiner
Turbo fuel "
Distillate "
Vacuum gas oil "
Residual fuel "

Cracking

High severity with zeolitic catalyst
Low " " amorphous "

Note that cat. cracking feedstocks include:

- 500/650°F heavy atmospheric gas oil plus light coker gas oil
- 650/1050°F vacuum gas oil plus coker gas oil

Hydrocracking of 650/1050°F vacuum gas oil to produce maximum distillate

Other Units

Cat. cracker light ends
Propylene and butylene alkylation (to make alkylate, a gasoline blending component)
Catalytic reforming (to make an aromatic gasoline blending component); feeds 160/310°F or 160/360°F naphthas
Hydrogen plant
Sulfur plant
Coker (to reduce the yield of heavy ends thereby increasing the availability of feedstocks available for upgrading via cat. cracking, etc.)

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16. ABSTRACT

This study examines the effects of changing the proportions of automotive distillate fuel and gasoline produced by refining petroleum. It provides a partial answer to whether a shift to increased distillate production, that would be necessary if there were a widespread use of vehicles requiring distillate fuel, would result in significant improvements in resource utilization. Calculations for a grass-roots refinery, that would come on stream in the 1990-2000 time-frame, indicate that the maximum theoretical energy saving is about 2% of the crude oil charged when approximately equal quantities of automotive distillate and gasoline are produced. Savings in refinery investment and manufacturing cost would be achieved, too. However, the external impacts of major changes in gasoline/distillate ratio need to be analyzed to establish the practicality of moving in the direction of equal quantities of distillate and gasoline. The impact on petrochemicals and other industries may be substantial.

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